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ABSTRACT

Multidisciplinary programs have a venerable history, but most of the early history was either at big university equipment projects or at first-rate industrial laboratories. There has always been a small amount of interdisciplinarity, such as the physicist's or chemist's cadging crystal specimens from the geologist. But only in the post World War II period have substantial multi-disciplinary projects flourished in American universities. Renewed interest in multidisciplinary programs in universities prompted the Working Group on the "Capacity of Academic Science and Engineering" of the Government-University-Industry Research Roundtable to choose such programs as one of its principal interests in 1985. The purpose of the paper is to assemble, in a necessarily personal fashion, perspectives from past multidisciplinary programs as an aid to designers and supporters of future programs. Discussed are opportunities for multidisciplinary approaches, the role of the academic department, and the principles and practices of successful multidisciplinary programs. (CW)

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MULTIDISCIPLINARY RESEARCH AND EDUCATION PROGRAMS IN UNIVERSITIES: MAKING THEM WORK

Robert L. Sproull
Harold H. Hall

Introduction

Renewed interest in multidisciplinary programs in universities has prompted this paper. The Working Group on the "Capacity of Academic Science and Engineering" of the Government-University-Industry Research Roundtable (1) chose such programs as one of its principal interests in 1985, approaching the topic through a series of discussions and consultations. The authors of this paper, as members of the Group, prepared an original working paper for the Group and have revised it to incorporate ideas from those interactions. The purpose of the paper is to assemble, in a necessarily personal fashion, perspectives from past multidisciplinary programs as an aid to designers and supporters of future programs. The authors express their gratitude for the inputs received, but remain responsible for the limitations and shortcomings of the final expression. (2)

Multidisciplinary (or interdisciplinary, adjectives which are deliberately used interchangeably throughout this paper) programs have a venerable history, but most of the early history was either at big university equipment projects (like the Berkeley cyclotrons which were heavily dependent on innovative electrical engineering, even if performed by "physicists" and directed toward physics output)

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or at first-rate industrial laboratories. There has always been a small amount of interdisciplinarity, such as the physicist's or chemist's cadging crystal specimens from the geologist. But only in the post World War II period have substantial multidisciplinary projects flourished in American universities.

It is worth noting at the outset that differences within an academic discipline can be as consequential as those between disciplines. The experimental solid-state physicist has less reason to interact in his research with the particle physicist than he does with the analytical or inorganic chemist. Many scientists and even a few engineers have been highly productive by brilliant contributions in a narrow field. But some scientists and almost all engineers flourish by avoiding building a fence around what they call their "field;" some have done this spectacularly, like Peter J. W. Debye, who was an electrical engineer, a mathematician, a physicist, and a chemist. Whether within an academic discipline or across disciplines, the absence of fences has much to recommend it. But whereas the spreading of one's wings to other fields in his discipline is easy and natural, the crossing of disciplinary boundaries involves institutional friction and restraints, and these are addressed in this paper.

The context for approaching multidisciplinary work is that of a university program supported in part by the federal government. If industrial companies are involved, so much the better, but the questions indigenous to university-industry contracts (patents, publication, foreign corporations, and such) are not addressed here; similarly, state participation can be a major plus but is not addressed. The policies, practices and culture of both universities and government agencies are important to this paper, but the principal obstacles (along with the creative strengths) will be found in the universities.

The taxonomy of multidisciplinary programs, however rich and rewarding in its own right, is not a focus of this paper. The focus is on a university multidisciplinary research and education program, supported in part by the federal government, that is operated through a formally organized continuing institutional body. We recognize and encourage less formal, less structured, and more spontaneous means by which investigators collaborate in their research. Such approaches, however, generally require less attention to the principles and practices that are the focus of this paper.

Current interest in technological and international competitiveness drives some of the renewed interest in the subject. Federal and state governments, industry and universities all promote multidisciplinary programs as a means to improve competitiveness. No implication is intended that interdisciplinary programs are either a necessary or a sufficient condition for improving competitiveness. The intent is to describe some of the problems in organizing, funding, and operating multidisciplinary programs in universities, to characterize some of the circumstances where a multidisciplinary approach may yield benefits not otherwise accrued, and to list key principles contributing to success of such efforts.

Opportunities

The expanding opportunities in multidisciplinary approaches in science and engineering are well recognized. Problem- and product-oriented research are necessarily multidisciplinary, and so is the creation of a technology base. There is considerable evidence that the part of scientific progress that ultimately will be applicable in some form to human needs will be heavily multidisciplinary. Fundamental science also is becoming more multidisciplinary in character. Murray Gell-Mann (3) has commented:

> *"It is usually said that ours is an age of specialization, and that is true. But....new subjects, highly interdisciplinary in traditional terms, are emerging and represent in many cases the frontier of research. These interdisciplinary subjects do not link together the whole of one traditional discipline with another; particular subfields are joined together to make a new subject. The pattern is a varied one and constantly changing."*

These remarks are not to take anything away from traditional single discipline areas like particle physics (with implications for cosmology and the "ultimate" structure of matter) but only recognize the obvious power and promise of heavily hyphenated research. This power is nowhere as evident as in biology, where the macroscopic manifestations (development, pathology, and creation of new chemical and biological agents) of molecular structures demand ever more sophisticated combinations of physics, chemistry, biology, applied biology (the art and science of medicine), and engineering.

There is a special opportunity in educating graduate students in an interdisciplinary environment. A graduate student should (in addition to amassing facts and acquiring tools) have the opportunity to see just how far his imagination can carry

him in a research project, and the heart of this thesis research is usually firmly in a discipline. But if he is immersed in a multidisciplinary setting while doing this, if he is encouraged by his environment to bring other disciplines to bear on his work and to explore the implications of his results for other disciplines, he can acquire a firm base for richer contributions to science and technology in his subsequent career.

The Academic Department

In the structure of the modern American university, the prominence and power of the academic department are both its greatest strength and (in our present context) a serious handicap. The department is absolutely necessary to sponsor, to promote, and to organize teaching and to serve as a vehicle for the faculty's participation in college and university affairs. It plays the key role in the quality control of staff and students; its close relation to its discipline on a worldwide scale is essential. The discipline (e.g. chemistry) is characterized by internal standards for teaching and for research, the latter depending on refereed journals and national and international societies. Although in the interdisciplinary world it is common practice to castigate departments and disciplines, it must be emphasized that they are absolutely vital not only to the university but, paradoxically, to multidisciplinary programs. The important trick is to build on the disciplines and not to let the departmental structure compartmentalize research and graduate education.

Recruiting, promotion and tenure are dominated by the department, and this circumstance poses well known and severe problems for those in multidisciplinary programs, especially young people. This is not the place to argue for tenure, although an excellent case can be made for it especially in the humanities and social sciences; perhaps in the natural sciences and engineering instead of lifetime tenure only the tenure characteristic of the better industrial laboratories would be more appropriate. But, in any case, a serious decision about "permanent" employment based on an individual's promise must be made early in his career, and key elements of that must be his concern and competence as a teacher and his soundness, imagination, and productivity in research in his discipline; the department is preeminently involved in both areas. This role is justifiable since multidisciplinary programs cannot be counted on to survive for 30 or 35 years, the typical period of a tenure commitment. Yet the interdisciplinary research, teaching, and leadership

must also be included in this process (else the young investigator cannot risk interdisciplinary participation), and there must be spokesmen for this "output" and competence just as there are for his work in the department and discipline. More of this later.

Much of what has been said above about the academic department bears repeating at the next higher level of university organization, the college administrative level. Great difficulty attends multidisciplinary research which crosses college levels if the deans do not bless and nourish the interactions.

Sometimes a multidisciplinary program evolves into a discipline, and this is a key element of scientific progress. Psychology in the nineteenth century and computer science in the twentieth are examples. This evolution is completely healthy, but it is also healthy for a multidisciplinary program to remain a program (like "space science") or to disappear after a few years. It is because of this required flexibility that one must insist on a disciplinary home-base for investigators to whom a university makes a lifetime commitment.

Some of Washington--parts of the National Science Foundation (NSF) and the National Institutes of Health (NIH)--is also organized on disciplinary lines. The long established relations of university faculty with their disciplinary colleagues in the federal agencies can complicate the creation of multidisciplinary programs, but this effect is minor compared to the university structure problem.

Principles and Practices

In this section appear those principles and practices that make a multidisciplinary program at a university succeed. The first four or five (the fifth is implied by the first) are essential, and the program is virtually guaranteed to fail if they are not present in a substantial way. The remaining elements are not essential, but their presence will materially help the program, make it more readily defended, and improve the lots of the participants.

1. *Non-departmental support.* It is essential that there be resources that the program adds that would not otherwise be available, that these continue year after year, and that they remain under the control of the multidisciplinary institution, not the participating departments. Only by this process can the program be perceived as non-threatening by the relevant departments and can the local director and his advisers have enough influence to make the program

flourish. To the extent that this "umbrella" contract provides multi-year funding, it will give the government more for its money since longevity of funding leads to efficiency and enhances the director's ability to accomplish creative research that could not have been accomplished by routine support of principal investigators within the disciplines. The umbrella, especially if long-lived, encourages the university to commit tenure-track appointments and prime space in the heart of the campus. The contract can be the sole research support of new investigators, but established people should, in addition, continue to get support from other agencies. This means that when the director says "no" it is only "no with the umbrella dollars," which makes for a much happier program, and it enables other federal agencies to take pride in the program. Incidentally, this principle of additional resources is the time-honored way foundations have made changes and opened new avenues in universities.

2. *Promising field.* The program must produce research at the cutting edge of fields recognized by the departments as important. No department should justifiably conclude that its people are being exploited to aid in research of exclusive interest to other departments. The program must address important scientific and technological questions, be open-ended technically, and be rich in connections with other research and (if possible) eventual applications. It should be a field where a modest effort can make a real difference and yet not be just a problem that once solved, will go away. It would be advantageous if the scale of research projects within the program were of "human scale" (such that a graduate student can have an individual thesis project rather than a piece of a large joint project) and if the research were such that the institution's administration and even Congress can understand and take pride in it.

3. *Departmental affiliation.* All but the most junior investigators (research associates) should be members of regular academic departments. They should be evaluated on their strengths in their disciplines. Nothing destroys a multidisciplinary program faster than the knowledge, or even the perception, that the participants have joined it because they were not able enough "to make it" in their disciplines. Exceptions may be required for the senior people who manage large and complex special apparatus or central research facilities and who have other special expertise.

4. *Strong departments.* Although strong departments make the program director's negotiating difficult, they are absolutely essential for the success of the program. The danger here precisely parallels that in the preceding principle. On the positive side, participation in the program by a department that is nationally recognized as strong and productive greatly enhances respect for the program.

5. *Local champion.* The support required by the first principle is unlikely unless some respected scientist or engineer commits a major fraction of his career to the program. This individual, the director of the program, must have unexceptionable credentials in his own discipline, must be respected by the relevant faculty, must be alert to Washington considerations, and must be adept at defending and promoting the program. He will continually be negotiating with his university administration, his federal agency, and his department chairmen to secure resources and to provide an auspicious setting for research and education. His principal aids are the umbrella contract and the "output" of the program. One of his principal problems is to make sure that participation in the program, especially on the part of young people, does not interfere with promotion, salary advancement, and tenure. He will usually enjoy the buttressing and support of an executive committee or other group of respected faculty and associate deans who can speak for their colleges. In order to attract the success-prone, it is necessary that the champion be given a high degree of delegated freedom to succeed (or fail) without perpetual interference from above.

6. *Strong institution.* The strength of the college or university and of its traditions is a major factor in the success of the program. It must be willing to take risks in committing faculty positions and space, and it will frequently have to borrow against uncertain repayment promises. It must not be frightened by innovations in contracting or easily be distracted by protests, the most benign of which will be envy by those who think the program has been unfairly favored. It, of course, should have good traditions in computing, library, and other facilities.

7. *Shared evaluation for hiring, promotion and tenure.* It is a great help if the institution already has a tradition of bringing in faculty from intellectually contiguous departments to evaluate cases for promotion or tenure. This process can then be used to factor into key decisions the individual's interdisciplinary research and education, along with the more "regular" teaching

and discipline evaluation. Nor should such shared evaluations start only when someone is proposed for tenure or promotion in his department; such considerations must be incorporated into the original hiring decisions for the multidisciplinary organization if its staff is not to be led down garden paths.

8. *Arenas for interdisciplinary interaction.* Much of the stimulating interaction among disciplines will be planned by the director and others, but much will be unplanned and informal. Centrally shared research facilities, libraries, computing centers, conference rooms, and lounges are important elements of a multidisciplinary environment. (A good case could be made that the faculty club is as important as the president's office in advancing the work of an interdisciplinary program, but there is not a chance of convincing Health and Human Services or Defense Contract Audit Agency auditors of that.) The collocation of people from different departments is of enormous help; their departmental affiliations are secure, and geography can be used to establish the working affiliation with those from other departments.

9. *Two-dimensional matrix.* An individual has his primary interactions at the intersection of a column (his department) and a row (his interdisciplinary program). In the column, he relates to his department chairman and department apparatus like committees. In the row, he relates to the program director and his associates and advisory apparatus. This degree of complexity seems to be tractable and tolerable for almost everyone. It is unwise to ask the same individual to take a substantial role in <u>two</u> interdisciplinary programs, in addition to his department role. The reason is that in the real world, there are higher order demands (such as the college and the university) which render more than two primary interactions unworkable. More than one departmental affiliation does not usually create a problem, and can frequently provide benefits.

10. *Refereed journals.* In many interdisciplinary areas, archival, refereed journals are appearing. They are helpful in many ways, especially in evaluating investigators since an article in such a journal cannot be withdrawn if one's standards improve, and each article reveals a great deal about the individual's taste and judgment in choosing research problems and his standards of what he considers a completed piece of research.

11. *Industry involvement.* If the area is rich in potential commercial applications, it is a considerable advantage to get industrial companies (preferably more than one) involved. Among the many advantages are the realism this contributes and the acculturation of graduate students to the industrial environment. If commercial applications are not plausible, it may be better to avoid industrial involvement.

12. *Federal program manager.* The program manager in the supporting federal agency is a key element in the program. If he has high aspirations for the program, defends it effectively in long-range terms, and commands the respect both of his superiors and of his university directors, the whole enterprise is auspiciously managed. He should be quickly informed of all interesting developments in "his" universities and should justifiably take pride in them.

13. *State involvement.* State contributions to the program help in attracting federal support and, if appropriate, industrial support. The new state science and technology programs focus on support for collaborative and multidisciplinary research. Such support contributes to achieving the first principle--non-departmental support for the program.

Concluding Remarks

Multidisciplinary programs should not be static but should be constantly evolving, as progress is made and as the outside world changes. Some may evolve, like computer science, into new disciplines. Others may disappear into the existing departments or expire for lack of funds; if the umbrella contract terminates, the program should terminate unless truly remarkable industrial or state support replaces it on appropriate terms. It is easier to drum up support for abandoned children than for abandoned multidisciplinary programs. Parts of a program may be spun off as individual projects or even as nuclei of new interdisciplinary programs.

Partly because of this evolution but also because as Aristotle said, "the unexamined life is not worth living," there should be an external review body for each multidisciplinary program. Although it might be convened annually for interim "readings," its real value would come from a more secular review, say once every five years.

Measurement of the degree of success of multidisciplinary programs is especially difficult, and little is known of dispassionate measurements with the possible exception of the NSF reviews of the Materials Research Laboratories in 1972 and a review by MITRE in 1978 (4). Like educational experiments, these programs are almost invariably reviewed by their promoters (the standard approach for proving the theorem "all educational experiments succeed"). There is, however, good agreement as to how they should be measured. A knowledgeable, unbiased, uninvolved group should compare the "output" of research and educated people over a period of (say) 10 years with what they think the same resources would have produced if applied in the routine, individual-principal-investigator way. Such a comparison, of course, presents formidable difficulties.

In closing, two cautionary notes and an expression of faith are offered. Lord Kenneth Clark has said that creative periods in history occur only in periods of great confidence. The present period is characterized by a conflicting combination of confidence and doubt. It might therefore appear inauspicious for new, imaginative, creative enterprises like multidisciplinary programs. This observation need not be discouraging but only suggests caution and care in designing the programs.

The second cautionary note is a derivative of Principle 1 above. The thrust of that item was that a program would not be given even a fighting chance on a campus if resources for it were evidently obtained at the expense of existing disciplinary research support. To a lesser, but still appreciable extent, this principle applies also on the national scale. If new interdisciplinary programs are established during a budget retrenchment period, evidently at the expense of other research support, the national program would be perceived as parasitic. This is less of a problem than if the zero-sum game was played out locally, but it is still a problem. Again, this is not an argument for no new multidisciplinary initiatives, but only a caution that they should be conceived and designed very carefully for specific opportunities.

The expression of faith is that the opportunities for multidisciplinary programs are great and growing, and even in unusually tight budget circumstances, a few carefully chosen programs would be an excellent use of federal funds.

References and Notes

1. The Government-University-Industry Research Roundtable is sponsored by the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. It was created in 1984 to provide a forum where scientists, engineers, administrators, and policymakers from government, universities, and industry can come together on an ongoing basis to explore ways to improve the productivity of the nation's research enterprise. See also Colin Norman, *Science*, volume 224, page 697, May 18, 1984.

2. We wish to thank our colleagues in the Roundtable Working Group for their criticism and comment, and Linda S. Wilson and William C. Kelly of the University of Michigan for helpful suggestions. Members of the Working Group are listed in Attachment I.

3. Murray Gell-Mann, *Emerging Syntheses In Science: Proceedings of the Founding Workshops of the Santa Fe Institute*, edited by David Pines, 1985, Santa Fe Institute, Santa Fe, New Mexico.

4. James G. Ling and Mary Ann Hard, *Science*, volume 209, page 1203 (1980).

Attachment I

ROUNDTABLE WORKING GROUP ON CAPACITY OF ACADEMIC SCIENCE AND ENGINEERING

Members

ALVIN W. TRIVELPIECE, (Chairman), Director, Office of Energy Research, U.S. Department of Energy (until 4/87)

ROBERT L. SPROULL, (Vice-Chairman), President Emeritus, University of Rochester, Department of Physics & Astronomy

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